

# Cutting Edge Technologies for Bioenergy

- **2011 Kentucky Agricultural Summit**
- **November 17, 2011**



# Outline

- **Feedstocks**
- **Bioenergy – heat and power**
- **Biofuels**
  - **Biorefinery**
  - **Thermochemical conversion**
  - **Biological conversion**
  - **Bio-oils**
- **Torrified wood**
- **Nanocrystals**



# The Opportunity & Potential



## Forest Biomass Feedstock

- Forest Residues
- Hazardous Fuel Treatments
- Short Rotation Woody Crops
- Wood Waste

## Conversion Processes

- Manufacturing
- Co-firing
- Combustion
- Gasification
- Enzymatic Fermentation
- Gas/liquid Fermentation
- Acid Hydrolysis/Fermentation

## USES

### Fuels:

- Renewable Diesel
- Ethanol

### Electricity and Heat

### Biobased Products

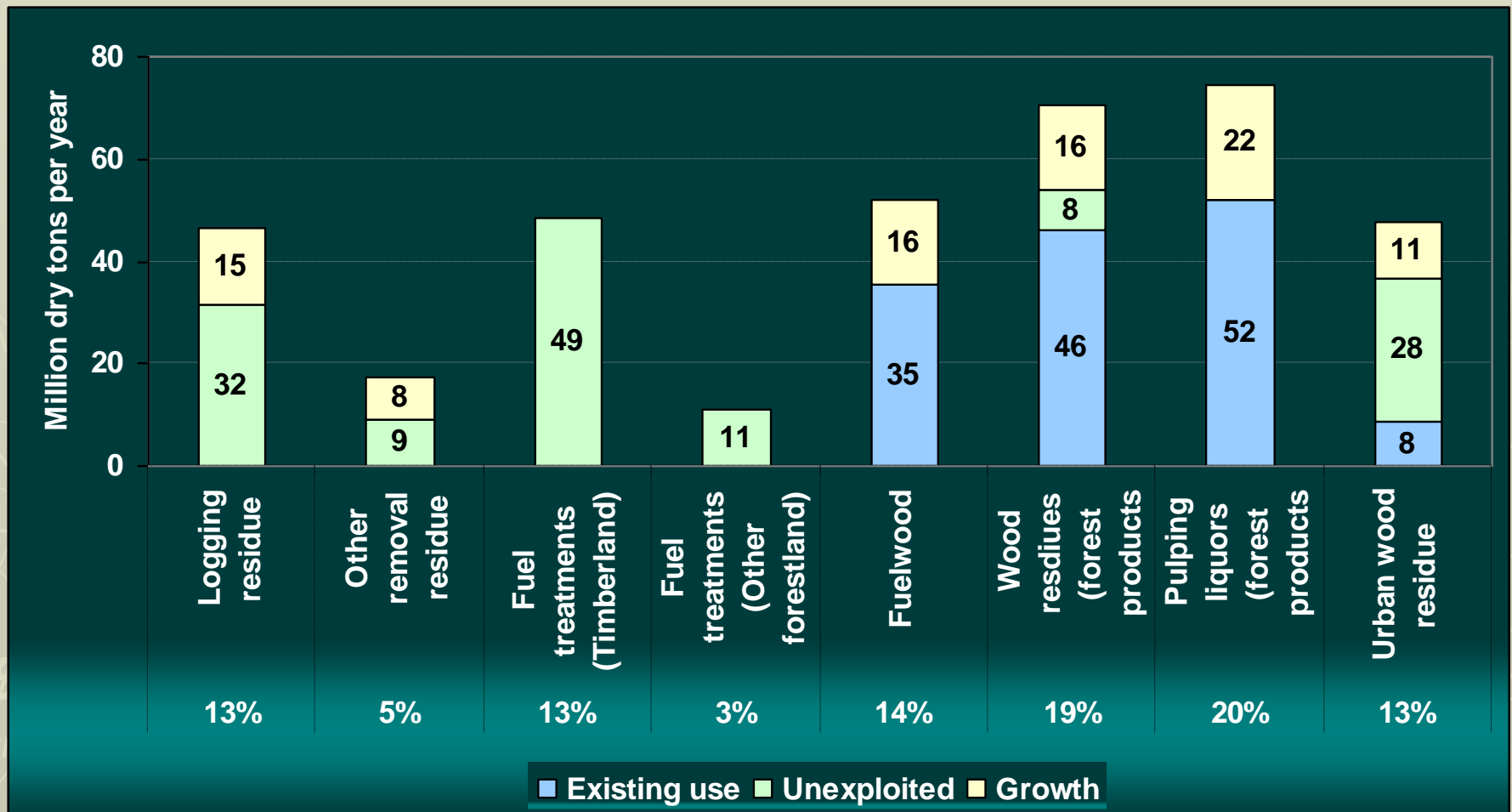
- Composites
- Specialty Products
- New Products
- Chemicals
- Traditional Products

# Green tons and jobs\*

- ▶ **362,600 green tons**
- ▶ **Assuming \$10/green ton**
- ▶ **Direct jobs 30**
- ▶ **Indirect jobs 27**
- ▶ **Total revenue output \$7,786,779**

# Forest Resource Analysis

**The sustainable forest resource potential for energy is nearly 370 million dry tons annually**



# Woody Biomass Energy

- **Can help reduce dependence on foreign oil**
- **Help provide outlet for thinnings from hazardous fuel treatments**
- **Reduce cost for hazardous fuel treatments**
- **Can be cost effective alternative**
- **Electricity generally costs 8 to 10 times more per unit of energy than wood chips; oil costs roughly 2 – 2.5 times, natural gas is currently only a little more expensive than wood chips**



# **Biomass Energy**

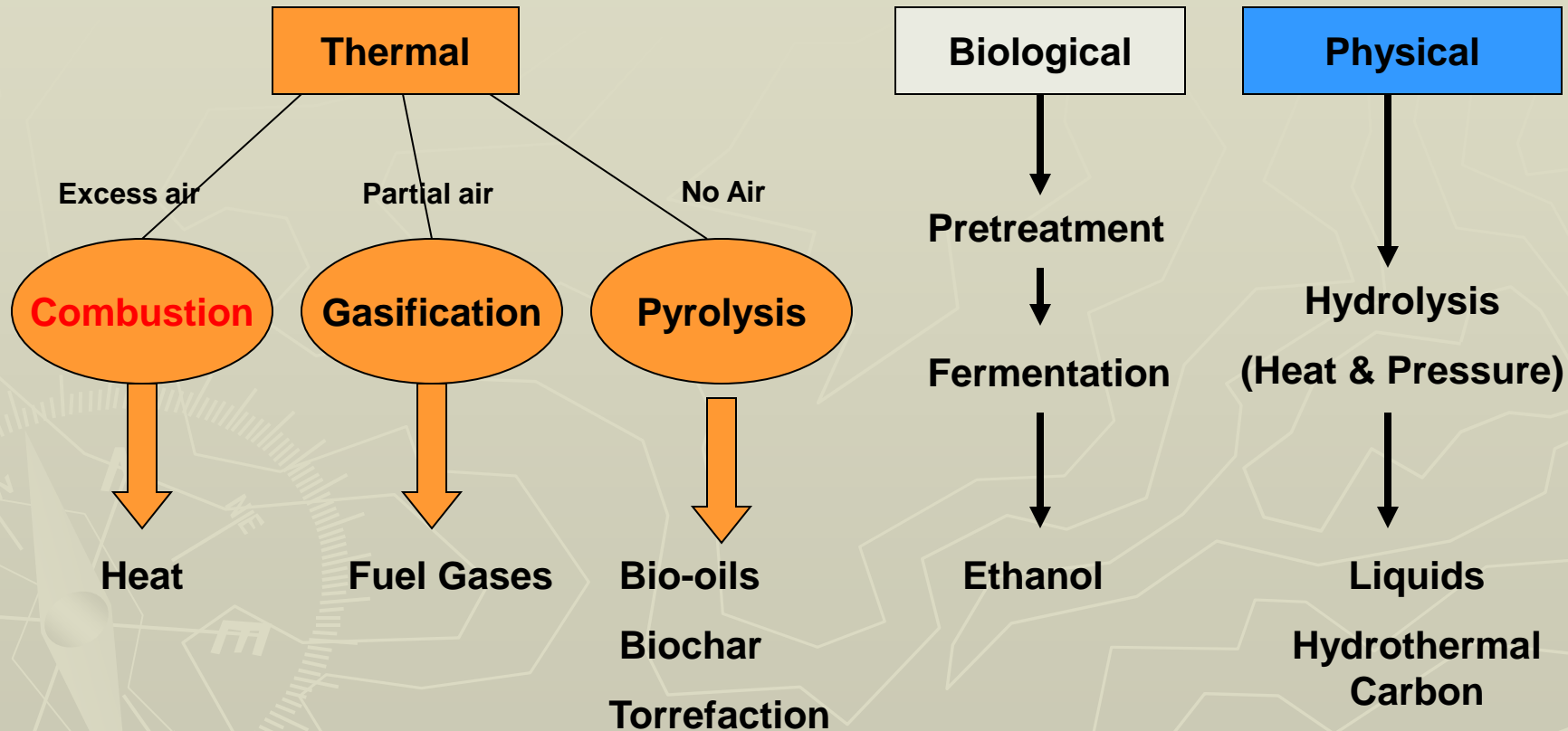
## **▶ Commercial biomass fuels**

- **Whole-tree chips – 4500 Btu/lb**
- **Mill chips (primary) – 5100 Btu/lb**
- **Switchgrass – 6740 Btu/lb**
- **Pellets – 8250 Btu/lb**
- **Agriculture residue – 5800 Btu/lb**

## **▶ Environmentally sound**

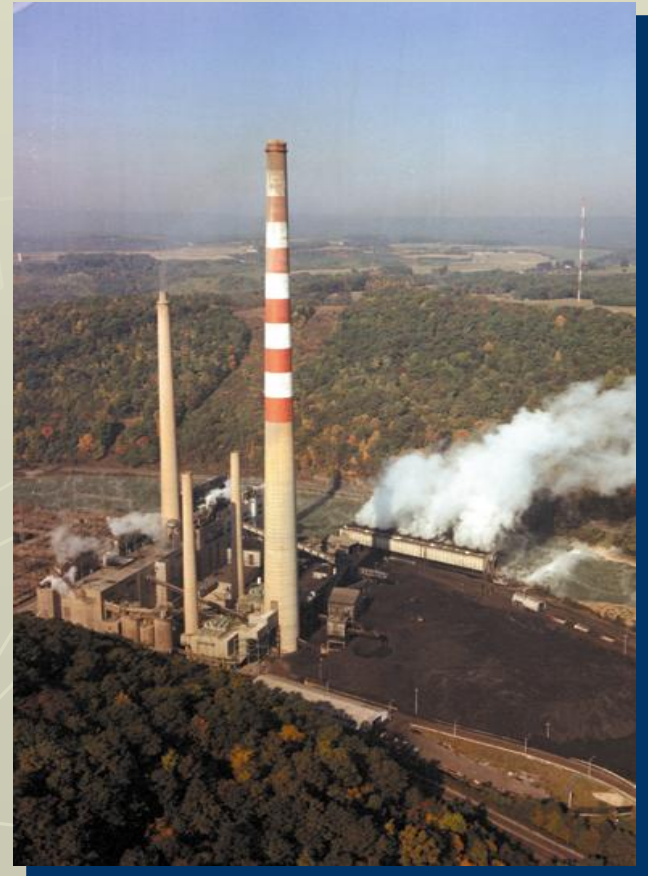
- **Carbon dioxide vs. methane production (20X)**
- **Minimal sulfur and heavy metals generation**
- **Renewable fuel source**

# Biomass Energy Pathways



# Status of Biopower in US

- **Currently Installed:**
  - **U.S. Biomass Power: 10,500 MW**  
(or about 8% of all non-utility generating capacity)
  - **7,000 MW from biomass residues**
  - **Over 500 facilities in U.S. generate electricity from wood or wood waste**



# Biomass Power

- Combined heat and power plant in St Paul, MN
- 25 MW of power
- District heating and cooling to downtown
- Off the shelf technology

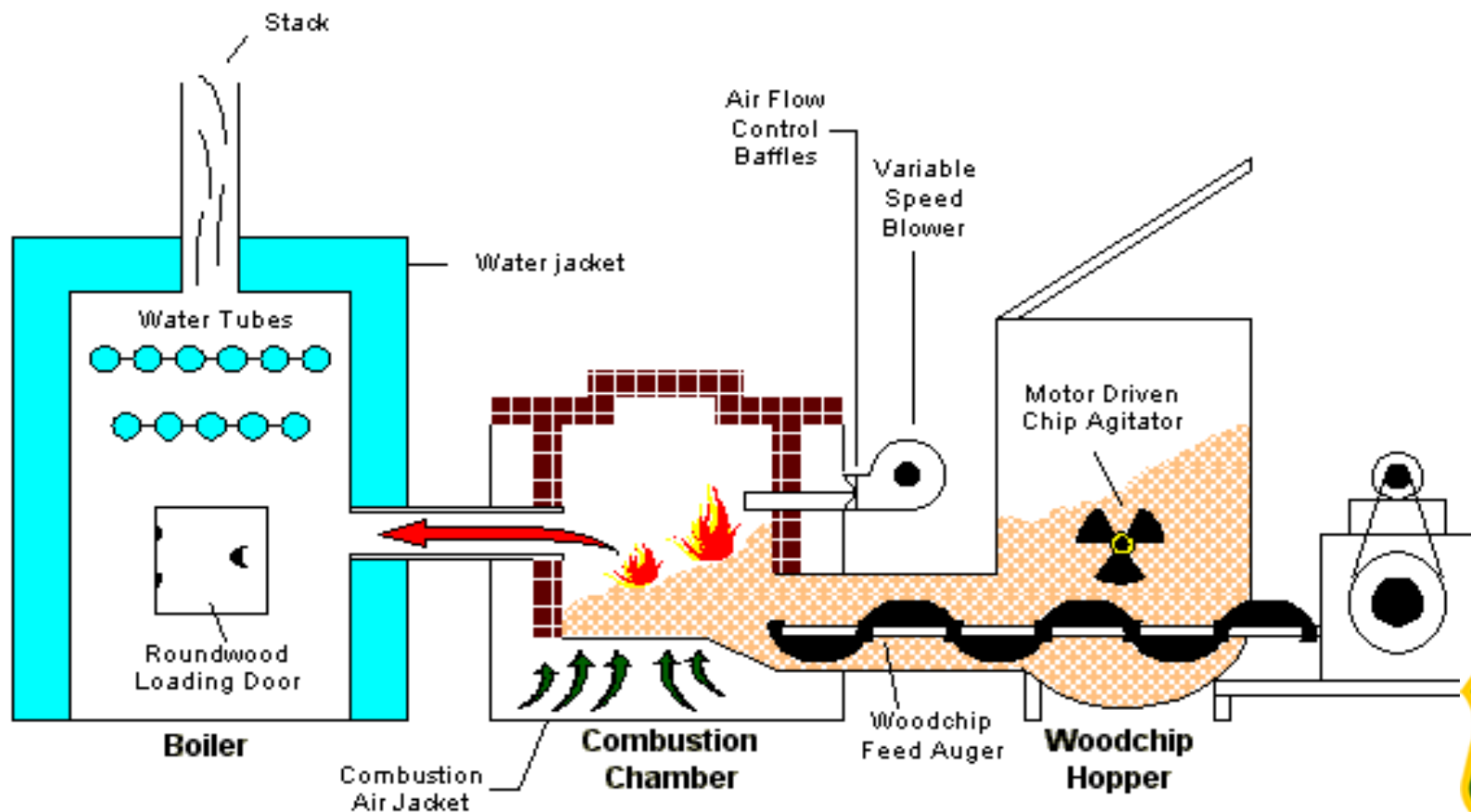


## Power Plant Size and Thinning Requirements

Thinning Radius  Miles	Total Area		Percent Thinning Required 10 year cycle		
	Sq. Mi.	Million Acres	1 MW	10 MW	50 MW
10	314	0.201	3.5	35	NA
25	1964	1.257	0.56	5.6	28.0
50	7854	5.026	0.14	1.4	7.0

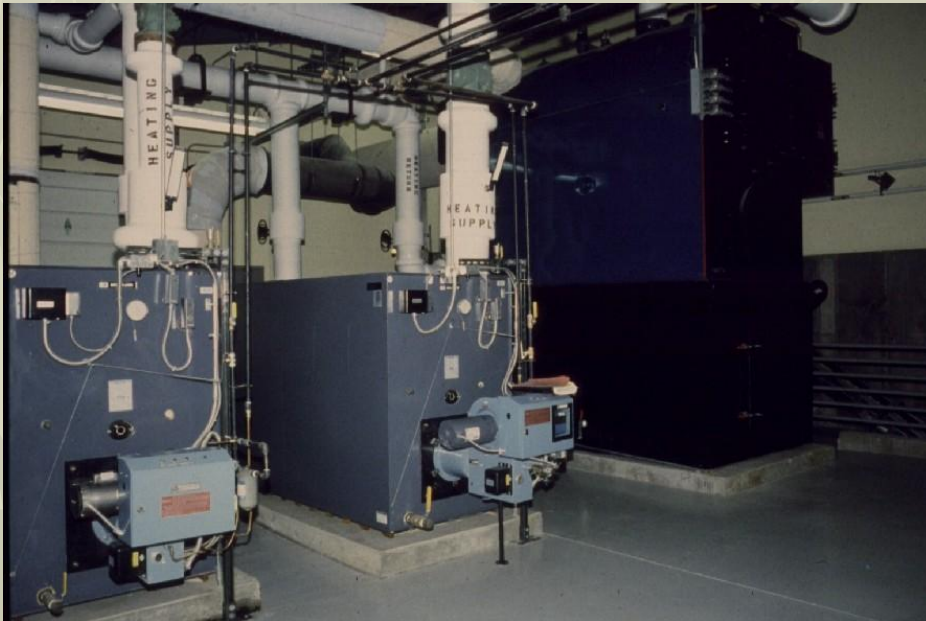
Based on 10 dry ton/acre/yr (20green ton/acre/yr)

# Small Commercial Bioenergy System



# Institutional Uses

- ▶ **Schools**
- ▶ **Factories**
- ▶ **Hospitals**
- ▶ **Rural communities**
- ▶ **State buildings (Vermont)**



# Small-Scale Wood Combustion

## Typical features

- **3 million Btu per hour (900 kW) output**
- **850 pounds per hour (green) fuel input**
- **45% moisture content (wet basis)**
- **20:1 turndown ratio (Divide the maximum energy output by the minimum energy output at which efficient, smoke-free combustion can be sustained)**



# Small-Scale Unit Cost Estimation

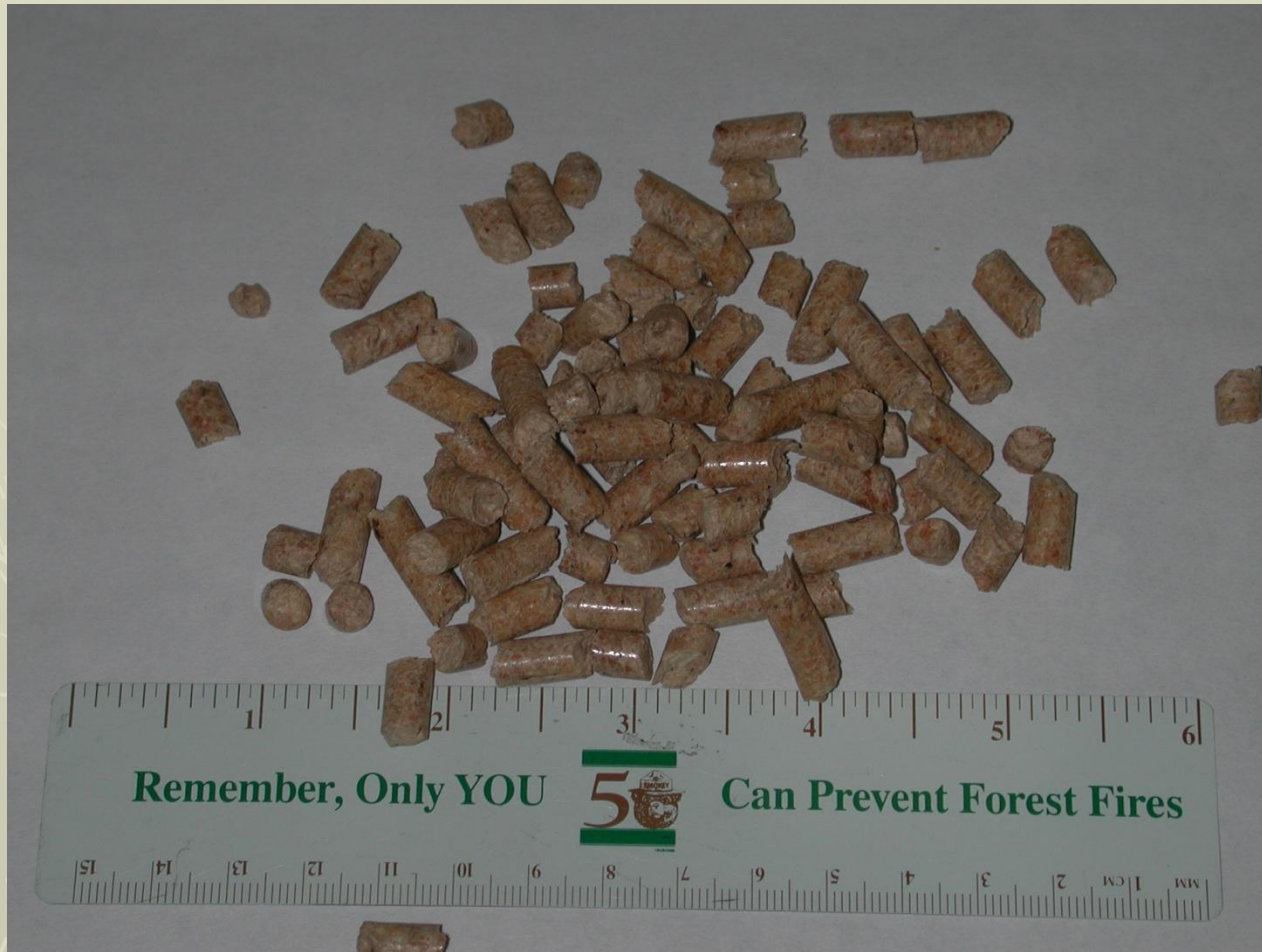
## ► Initial capital costs

- \$50 to \$75 per pound of steam generated per hour
- Biomass system capital costs are the highest of any fuel
  - Fuel handling system
  - Fuel storage
  - Low energy density fuel compared to fossil fuels

## ► Annual Cost

- Full-life cycle vs. payback
- Wood is typically the cheapest fuel available in many regions

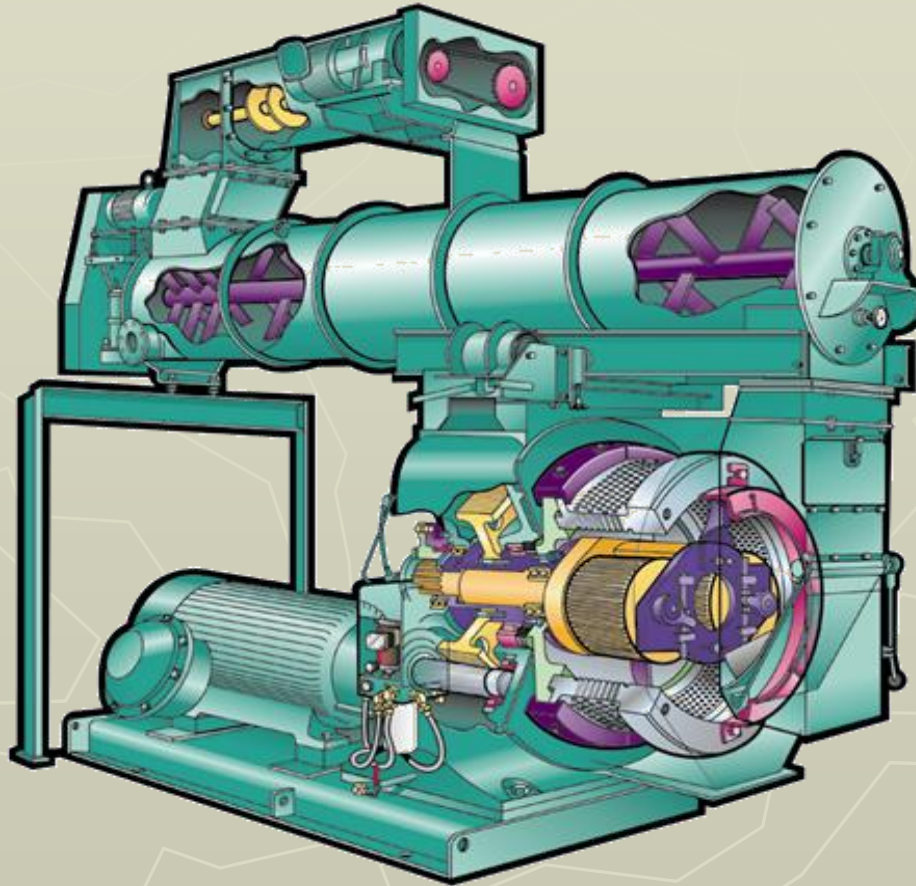
# Wood Pellets



- Sawdust
- Large export market
- NA produced 7 million tons in 2009, 5 million exported to Europe
- Bagged or bulk
- Pellet furnaces



# CPM Pellet Mills



# Equipment Summary

	<b>1 TPH</b>	<b>2.5 TPH</b>	<b>4 TPH</b>
<b>Hammermill, Feeder</b>	<b>\$40,644</b>	<b>\$43,114</b>	<b>\$56,007</b>
<b>Air assist discharge system</b>	<b>\$20,373</b>	<b>\$21,480</b>	<b>\$23,804</b>
<b>Pellet Mill, Conditioner, Feeder</b>	<b>\$119,613</b>	<b>\$178,570</b>	<b>\$277,519</b>
<b>Cooler, Air system</b>	<b>\$45,949</b>	<b>\$45,949</b>	<b>\$45,949</b>
<b>Rotex Screener</b>	<b>\$7,831</b>	<b>\$9,554</b>	<b>\$13,999</b>
<b>TOTAL</b>	<b>\$234,410</b>	<b>\$298,667</b>	<b>\$441,082</b>



# Pellet Systems

- Fuel more costly
- Storage smaller, cheaper
- Boiler smaller, cheaper



# Wood Pellet Furnance



Traeger Pellet Furnace

- **Pinnacle Stove Sales from Canada**
- **Manufacturer of Traeger Pellet Furnaces**
- **70,000, 85,000, 130,000, and 400,000 BTU units**
- **New England Pellet Mill starting to import into US**



# Wood Pellet Boilers



**50,000 to  
80,000 BTU/hr**

**European  
Made  
Pellet  
Boilers**



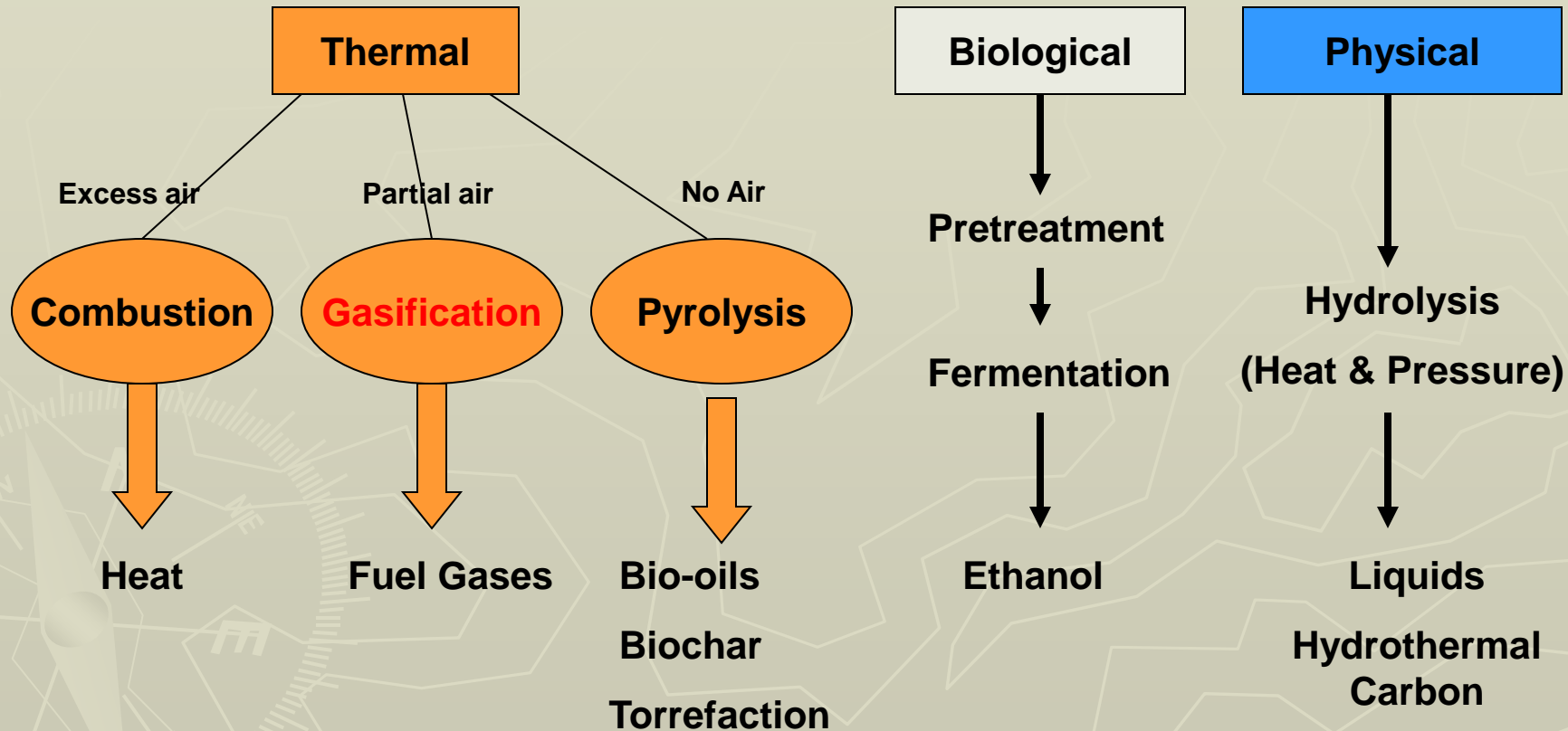
**1.7 MMBTU/hr**



**50,000 to  
120,000 BTU/hr**



# Biomass Energy Pathways

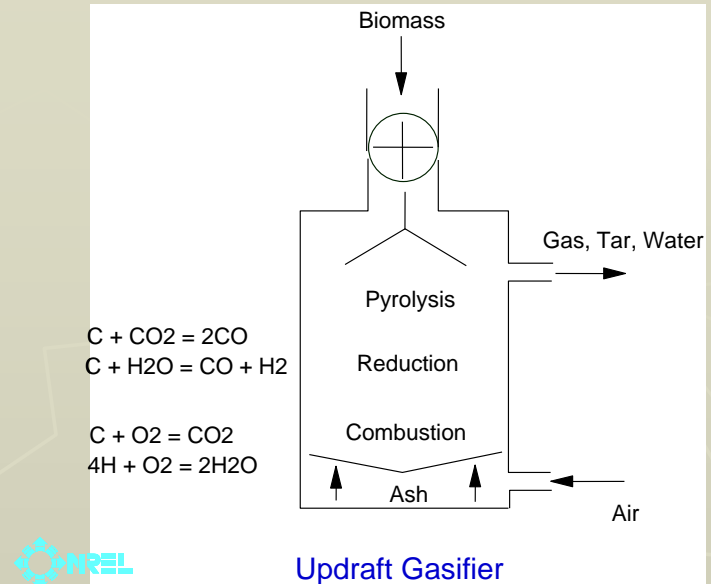


# Gasification

- **More efficient than combustion, 30-35%**
- **Effectively manages mineral matter**
- **Fuel gas ( $\text{CO} + \text{H}_2 + \text{CH}_4$ ) can be used in prime movers**

# Updraft Gasifier

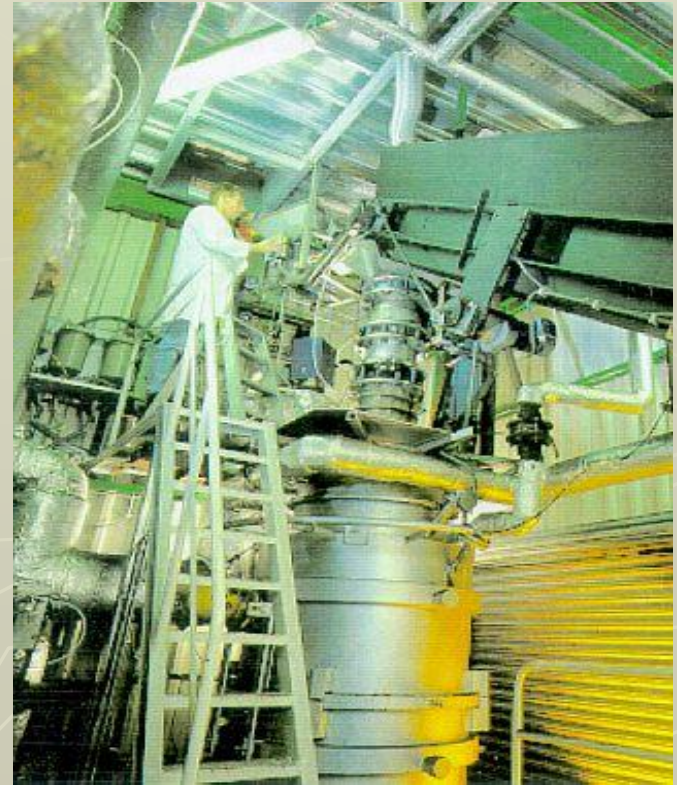
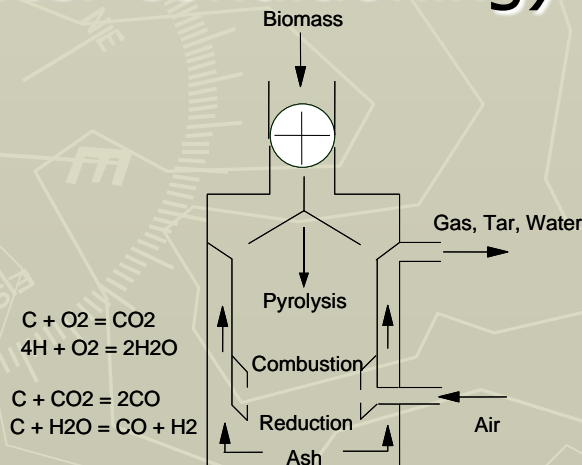
- Simple, reliable
- Commercial history
- High tars
- Close coupled combustion



Source: Renewable Energy Corp. Ltd (Waterwide Technology)

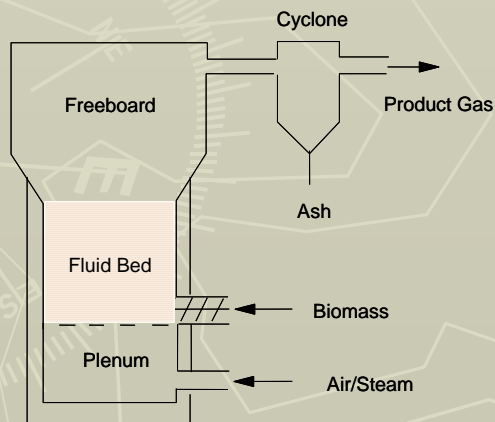
# Downdraft Gasifier

- Requires low moisture (<20%)
- Lowest Tar
- Can use gas in engines (after conditioning)



# Fluidized Bed Gasifier

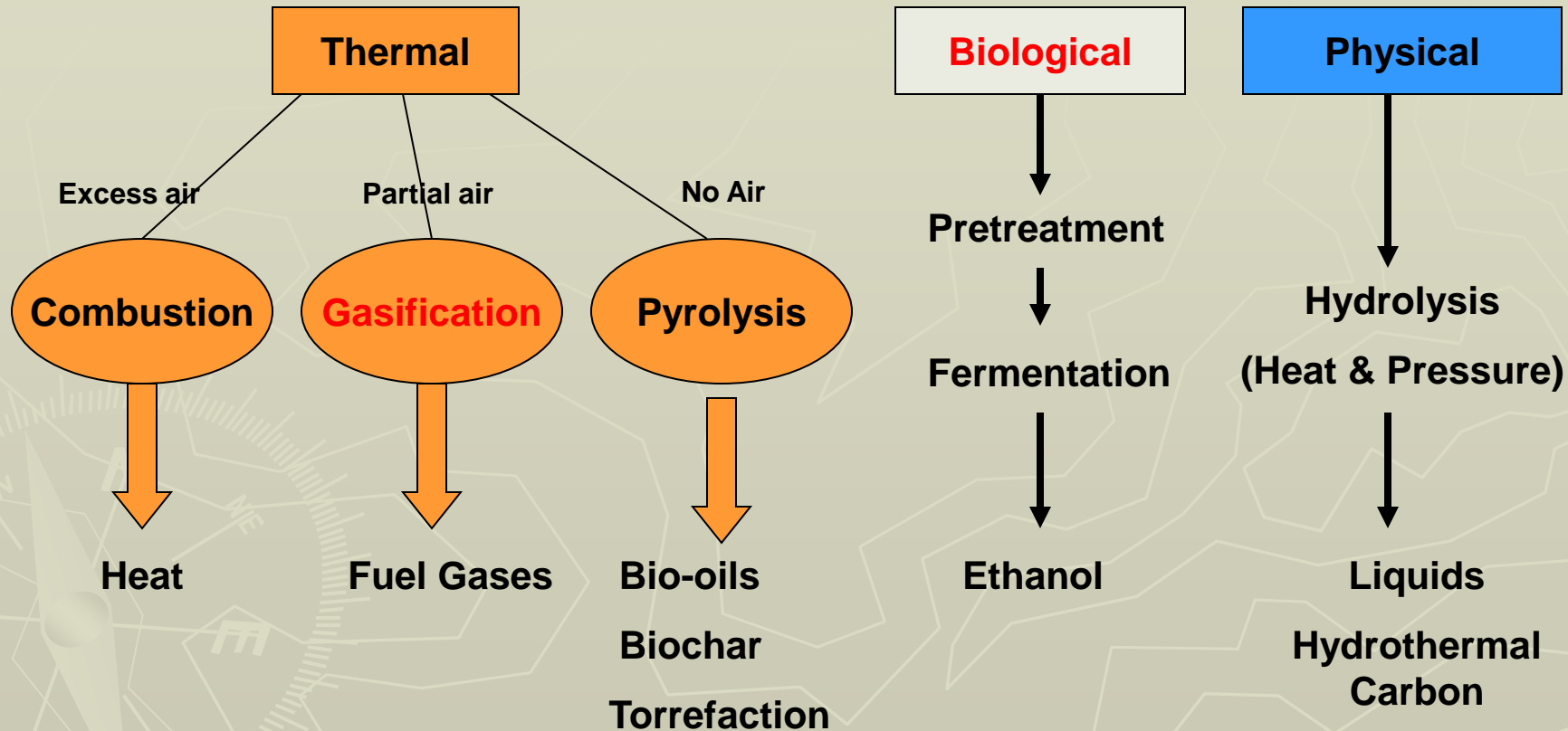
- Highest throughput
- Fuel flexible
- Tolerates moisture
- Complex operation



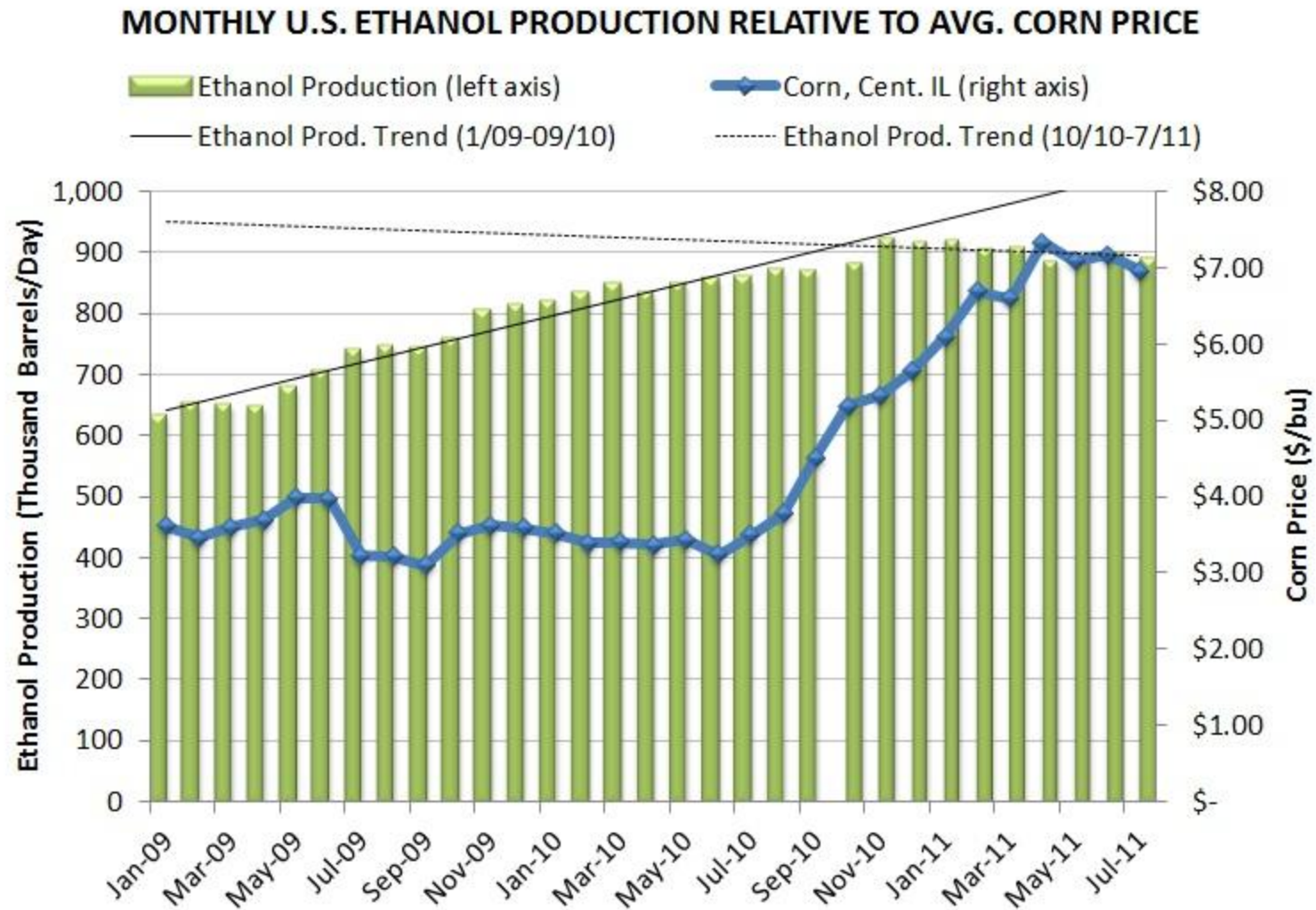
# Gasification Technical Issues

- Emissions (NO<sub>x</sub>) at small scale
- Gas Conditioning
  - Tars
  - Particulates (< 2 micron in size)
  - Acid gases ( H<sub>2</sub>S, NH<sub>3</sub>, HCN, HCl)

# Biomass Energy Pathways



# Current Ethanol Production



# Barriers to Woody Biomass for Ethanol

- **High thinning costs**
- **High transportation costs**
- **Low quality of material, including bark and dirt**
- **Costly to breakdown cellulose**
- **Low cost of oil (\$140 vs \$90)**



# Technologies to convert wood to biofuels

- **Thermochemical conversion**
  - Input: **chips with bark** (mill residue, tops/ branches/ whole tree chips, short rotation hardwood crops **or pulping liquor**)
  - Processes/outputs
    - Gasification
      - gasification to syngas – mix of CO, CO<sub>2</sub>, H<sub>2</sub>
      - catalytically convert syngas to biofuels & chemicals
    - Pyrolysis
      - Bio oil – refine bio oil into transport fuels and chemicals
- **Biochemical conversion**
  - Input: **clean chips** (pulpwood, short rotation hardwood crops)
  - Processes/outputs
    - Extraction of sugars from wood (+ chemical byproducts)
    - Fermentation of sugars to ethanol; use lignin for energy
    - Extract hemicellulose from wood prior to pulping
    - Extract and process sugars from clean chips
    - Catalytic conversion to polyols



# Liquid Fuel - Thermochemical

- Thermal treatment to produce a synthesis gas (mostly  $H_2$  and  $CO$ )
- Fischer-Tropsch reaction with catalyst
- Convert low BTU gas into methanol, diesel, gasoline, etc (max fuel yield – 200 gal/ton)
- Pilot plant stage in US

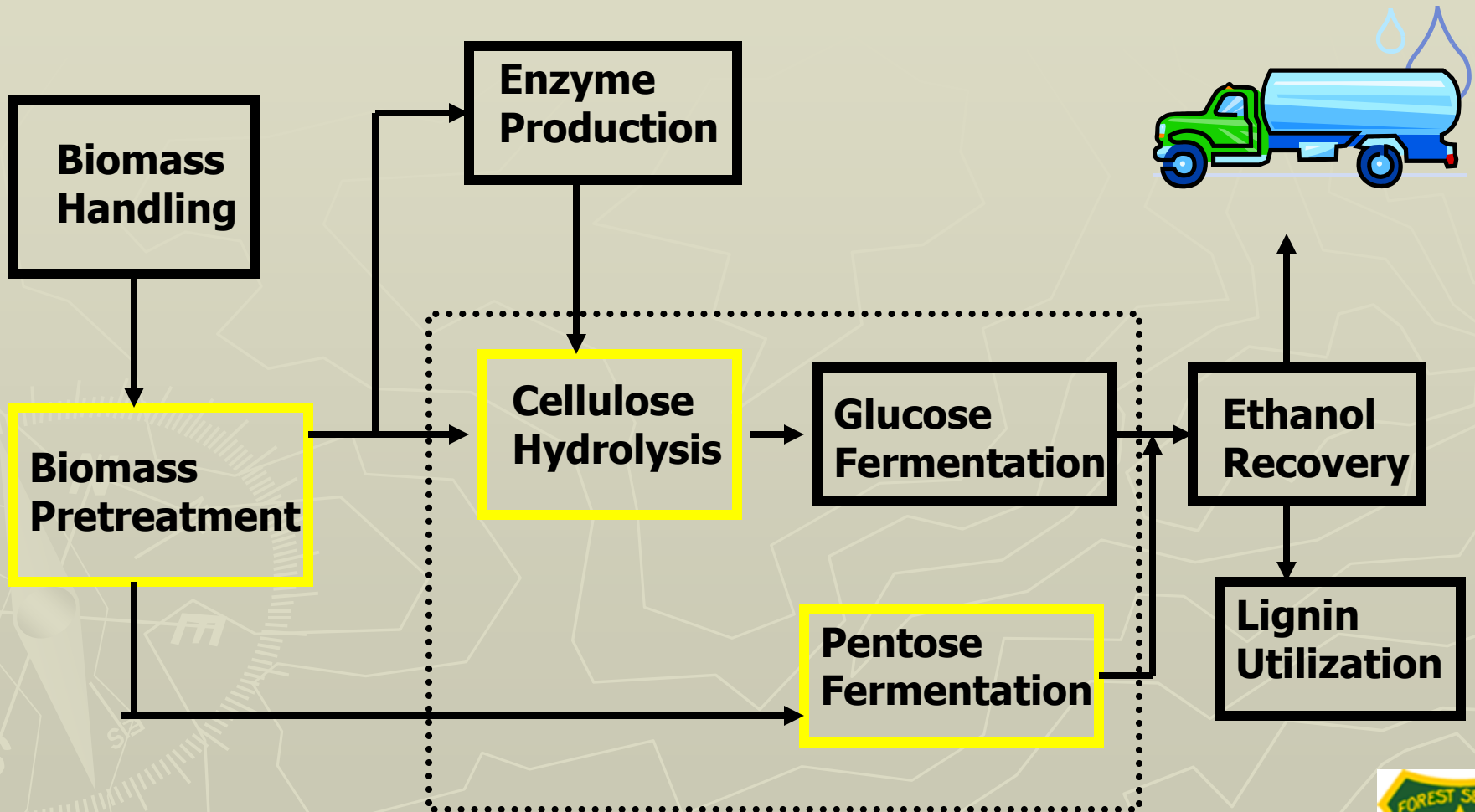


# Ethanol - Fermentation

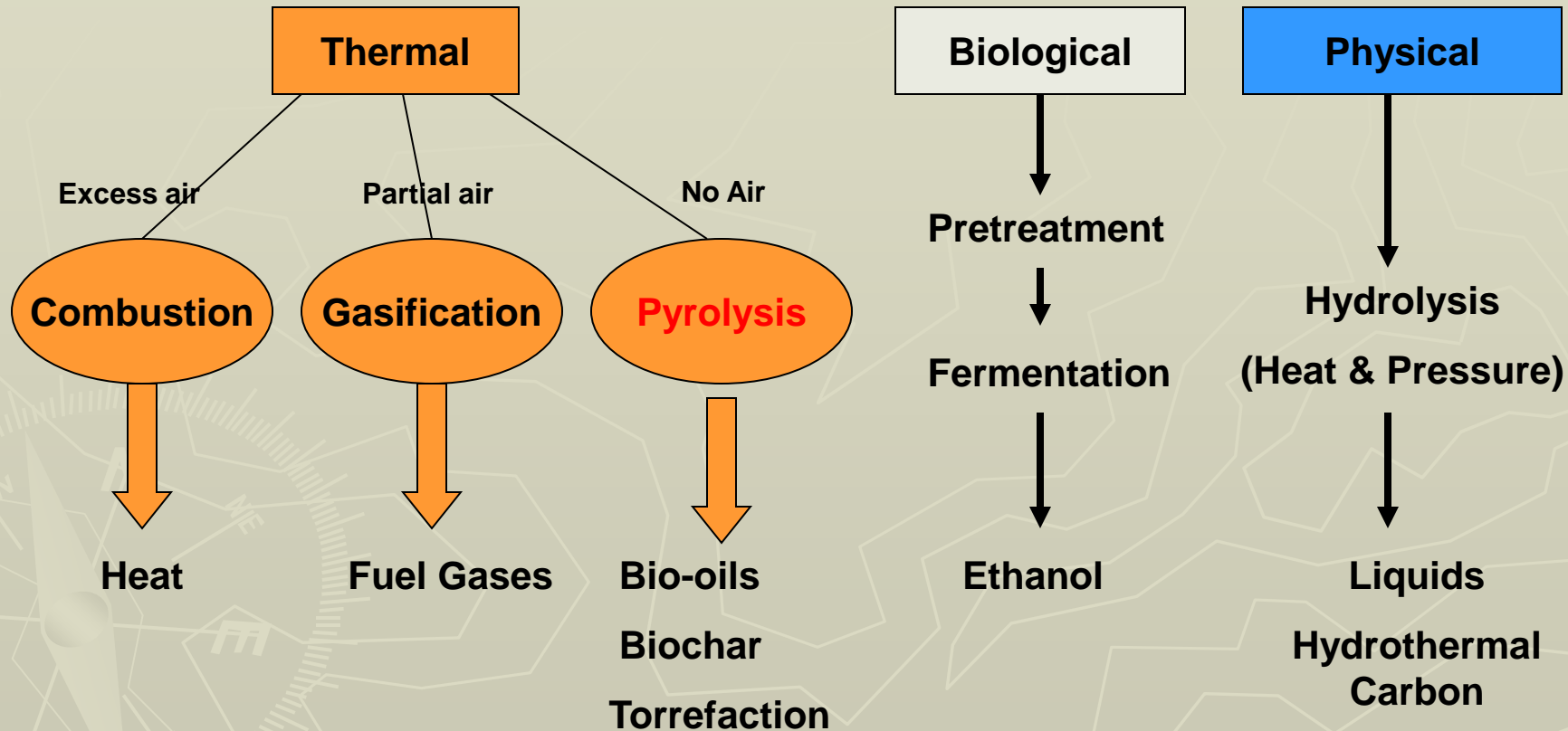
- **Current yield from lignocellulose 65 gallons/bone dry ton**
- **Steps include:**
  - Pretreatment of chips
  - Enzymatic treatment
  - Fermentation
  - Distillation
- **Yield may increase to 80 gallons/ton with enzymes to ferment 5-carbon sugars**



# Ethanol from Cellulosic Biomass



# Biomass Energy Pathways

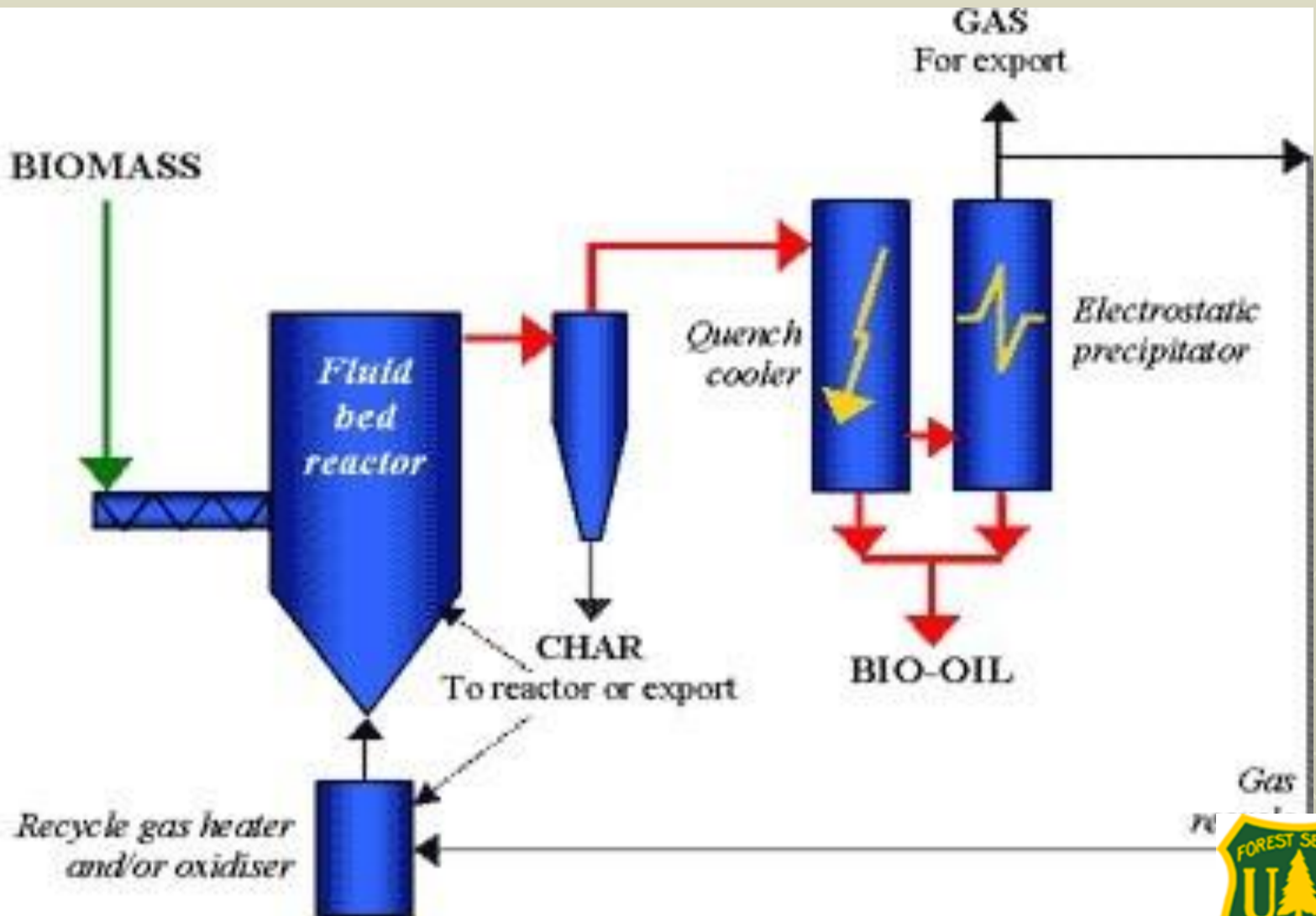


# Bio-Oil

- ▶ **Fast or flash pyrolysis**
- ▶ **Heating solid fuels at temperatures between 350 to 500°C for short period of time (2 sec)**
- ▶ **Bio-oil currently only used for electricity generation as substitute for light fuel oil**
- ▶ **Half the heating value of conventional fuel oil (16-18 MJ/kg)**
- ▶ **60% biooil, 20% biochar, 20% syngas**
- ▶ **2 commercial systems – Ensyn Group and DynaMotive Energy Systems**



# Bio - Oil



# BioOil Fuel Comparisons

	BioTherm BioOil	Light Fuel Oil	Heavy Fuel Oil
Heat of combustion BTU/lb	<b>7,100</b>	<b>18,200</b>	<b>17,600</b>
Heat of combustion MJ/liter	<b>19.5</b>	<b>36.9</b>	<b>39.4</b>
Viscosity (centistokes) 50°C	<b>7</b>	<b>4</b>	<b>50</b>
Viscosity (centistokes) 80°C	<b>4</b>	<b>2</b>	<b>41</b>
Ash % by weight	<b>~0.02</b>	<b>~0.01</b>	<b>0.03</b>
Sulphur % by weight	<b>Trace</b>	<b>0.15 to 0.5</b>	<b>0.5 to 3</b>
Nitrogen % by weight	<b>Trace</b>	<b>0</b>	<b>0.3</b>
Pour Point °C	<b>-33</b>	<b>-15</b>	<b>-18</b>
Turbine NO <sub>x</sub> g/MJ	<b>~0.7</b>	<b>1.4</b>	<b>N/A</b>
Turbine SO <sub>x</sub> g/MJ	<b>0</b>	<b>0.28</b>	<b>N/A</b>

Source: DynaMotive, <http://www.dynamotive.com/biooil/whatisbiooil.html>



# Key Issues for Liquid Forest Biofuels

- **Cost/Economics**
  - **Delivered forest biomass costs (lower than delivered pulpwood costs)**
  - **Conversion Efficiency (high)**
  - **Capital costs (includes economy of scale)**
- **Scalability**
  - **The liquid fuels sector is very “large” relative to the biomass sector and displacement of even a modest share of petroleum use requires massive amounts of biomass**
  - **The biomass supply curve is upward sloping although its location can shift over time**
- **Selling Price**
  - **Price of Petroleum**
  - **Corn-derived ethanol**
  - **Other alternate fuels to include corn stover, switchgrass, & CTL**
- **Policy--Credits/Subsidies/Loan Guarantees**
- **Ethanol Transport and Distribution System/F-T**
- **End Use Infrastructure Availability (>E10)**



# Forest Products Industry Biorefinery Value Map

↑  
VALUE  
↑



SAW LOGS



PULP WOOD



BIOMASS



LUMBER



SLAB WOOD



WOOD CHIPS



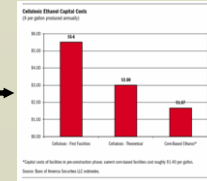
BARK



EXTRACTOR



EXTRACTOR/HOG BOILER/ GASIFIER/F-T



CHEMICALS



DIGESTER



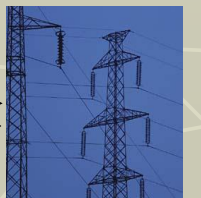
Liquid Fuels



PULP & PAPER

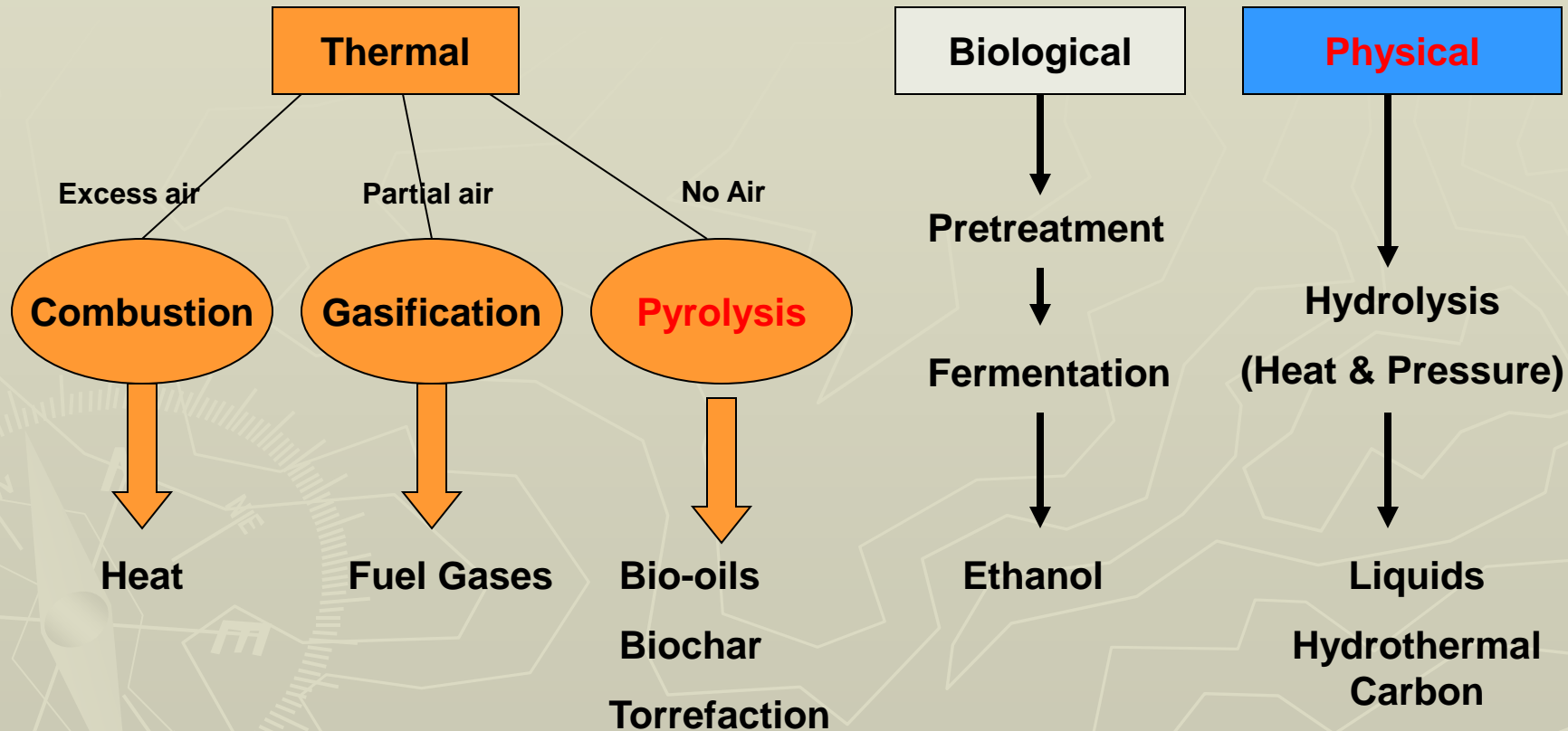


Black Liquor Gasifier



POWER

# Biomass Energy Pathways

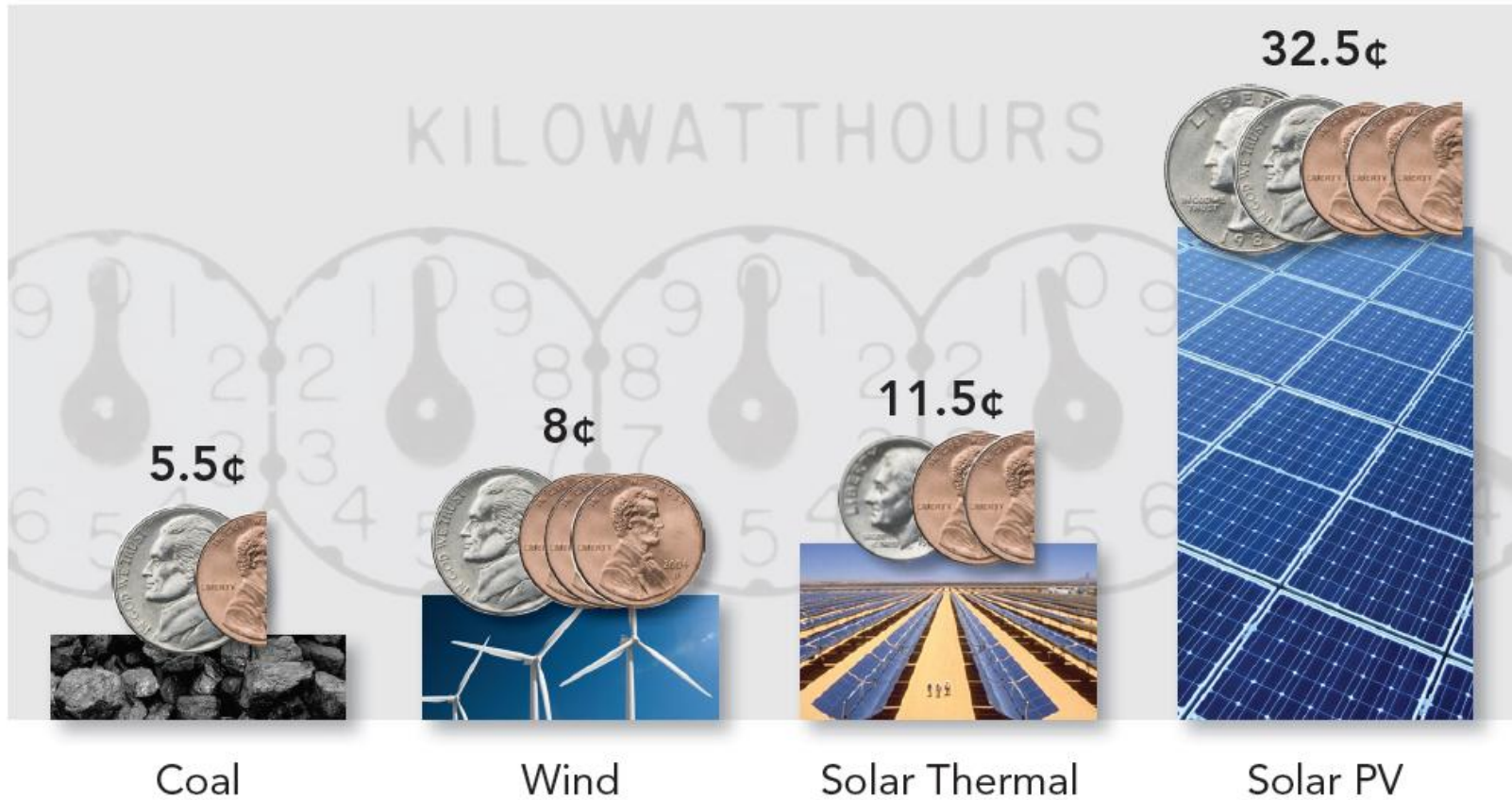


# **Renewable Portfolio standards**

- ▶ **Address electricity needs**
- ▶ **Impact coal fired power plants**
- ▶ **Address all renewable such as wind, solar and biomass**
- ▶ **Competition for biomass is not coal, but wind and solar**

# Cost of Electricity by Fuel Source

Cost in Cents per kW-h



# Cofiring with Coal

- ▶ **Existing infrastructure**
- ▶ **Many environmental benefits**
- ▶ **States with renewable portfolio standards driving interest**
- ▶ **10% Biomass before having to derate boiler**
- ▶ **Biomass chips don't pulverize like coal**

# Co firing with Coal

- ▶ **500MW coal fired plant uses 1.43 million tons of coal/yr**
- ▶ **Co-firing with 10% woody biomass BTUs = for corresponding BTU is 181,300 tons of oven dry woody biomass**
- ▶ **362,600 green tons = 35 semi loads/day at 50% mc**
- ▶ **Woody biomass does not mix well with coal and need separate handling system**
- ▶ **Too costly - need fuel that will pulverize with coal**

# What makes coal cofiring work

- ▶ **Energy dense as coal**
- ▶ **Sized and weight that approximates crushed coal**
- ▶ **Resists weathering**
- ▶ **Chemically stable**

# Ways to densify wood

- ▶ **Wood pellets**
- ▶ **Dry torrefaction (biochar) 1 Atm, 200-300°C**
- ▶ **Hydrothermal carbonization (Gas Technology Institute)**

# Thermochemical Routes to Biomass Densification

- ▶ **Torrefaction**
- ▶ **Hydrothermal Carbonization (HTC)**



**Woody biomass**



**Torrified biomass**



**Torrified wood pellets**

# Torrefaction

- ▶ **200 to 300°C in absence of oxygen**
- ▶ **Atmospheric pressure for 60 to 90 minutes**
- ▶ **Produces solid, frangible carbon-enriched product with low mc**
- ▶ **HHV – 8600 – 10,300 BTU/lb dry**
- ▶ **Combusts and gasifies like biomass**
- ▶ **Hard to pelletize**
- ▶ **Moisture resistance but moisture breaks up pellet**

# Properties of torrefied biomass

- **High energy density**
- **High water resistance**
- **Limited biological degradation**
- **Excellent grindability properties**
- **Good combustion properties**



# Application of torrefied woody biomass

- **Reduce transportation costs**
- **Co-firing with coal – can be pulverized and fed with pulverized coal**
- **Co-firing with gasifiers**
- **Pelletize for stoves**
- **Use as biochar for soil amendments**



# Hydrothermal Carbonization\*

- ▶ **Process with water at 200 to 260°C and 200 to 700 psia for <5 minutes**
- ▶ **Oxygen and hydrogen reduced but carbon is reduced much less than torrefaction**
- ▶ **HHV is increased by up to 36%**
- ▶ **Easily pelletized because of lignin chemistry**
- ▶ **Pellet resists water indefinitely**

# Energy Density

## Material

## BTU Content

BTU/lb

**Wood chips (50% mc)**

**4,500**

**Lignite coal**

**6,500**

**Wood Pellets**

**7,450**

**Oven dry chips**

**8,400**

**Dry torrefaction**

**9,400**

**Bituminous coal**

**10,650**

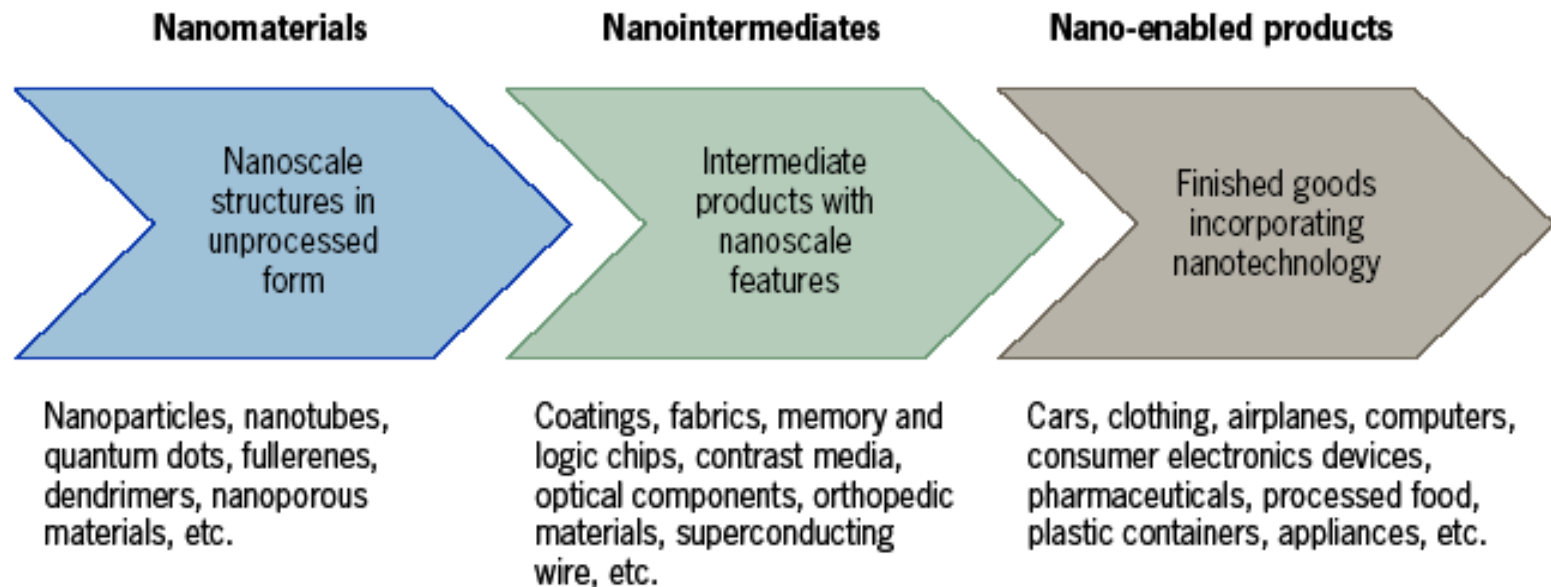
**Hydrothermal  
carbonization**

**11,400**

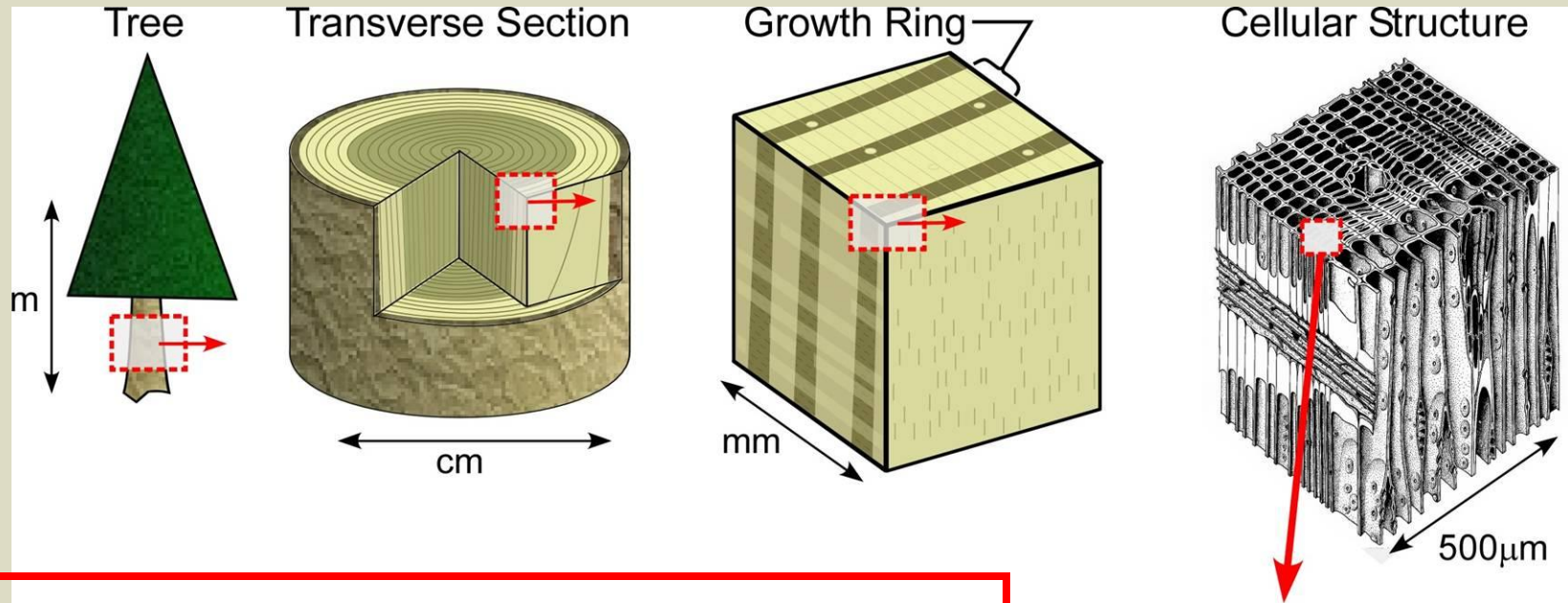
**Nanotechnology** *is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications.*

**Nanotechnology R&D** *is directed toward understanding and creating improved materials, devices, and systems that exploit these new properties.*

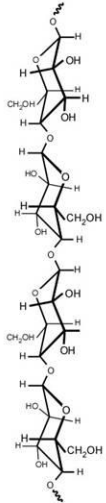
#### The nanotechnology value chain



# Size Scale of Lignocellulosics

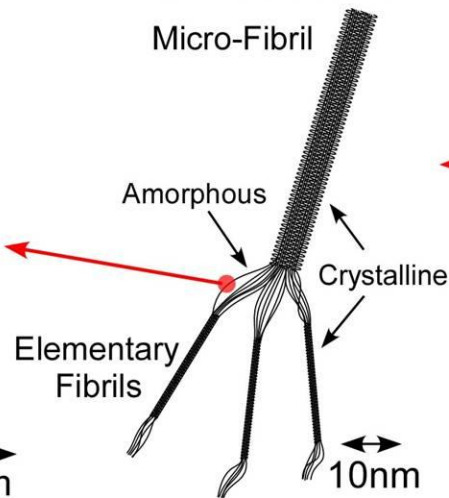


Cellulose

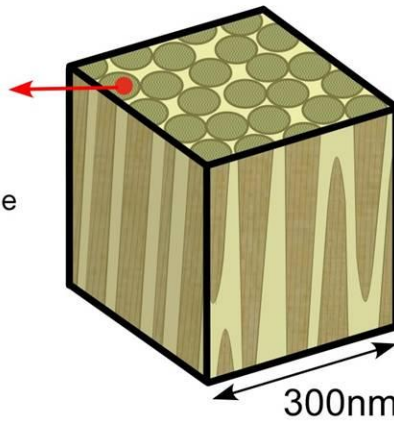


Fibril Structure

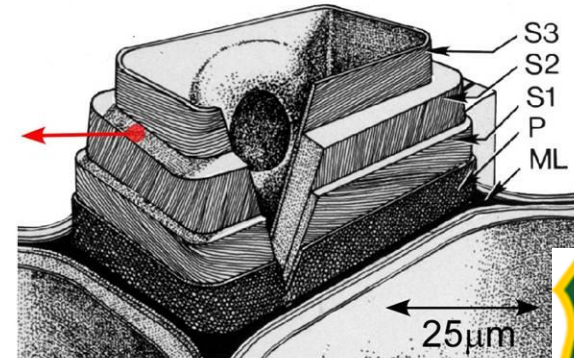
Micro-Fibril



Fibril-Matrix Structure



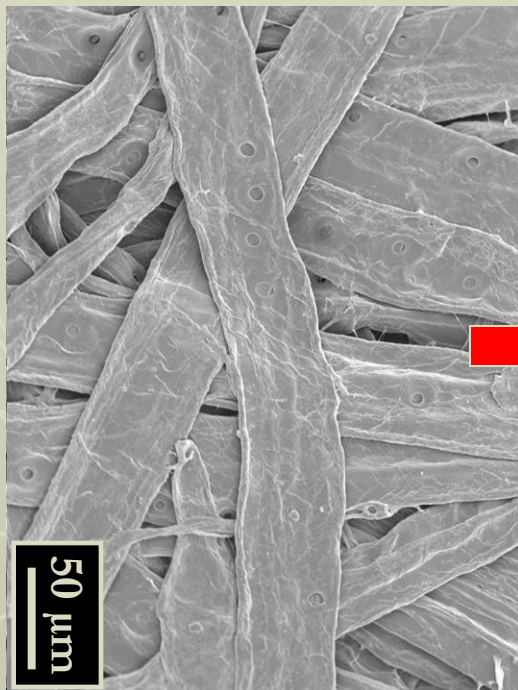
Cell Wall Structure



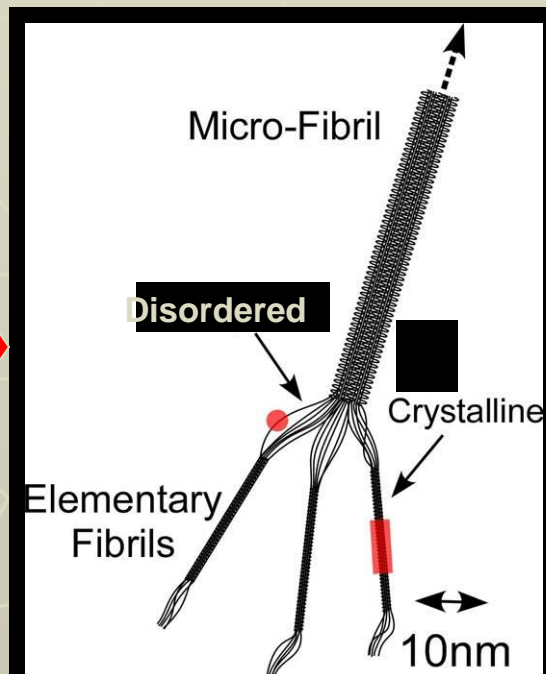
# Cellulose Nanocrystals

<sup>1</sup>Processing at US Forest Service Forest Products Laboratory (FPL)

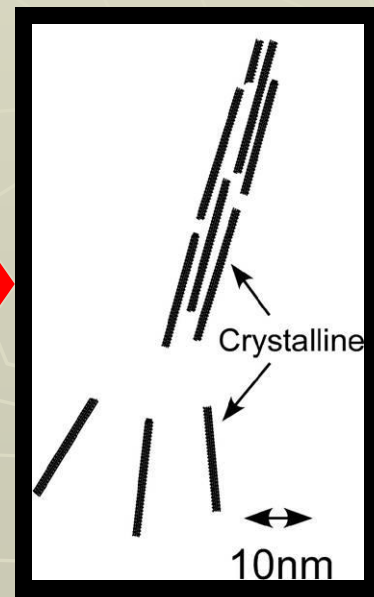
Pulp



Microcrystalline



Nanocrystals



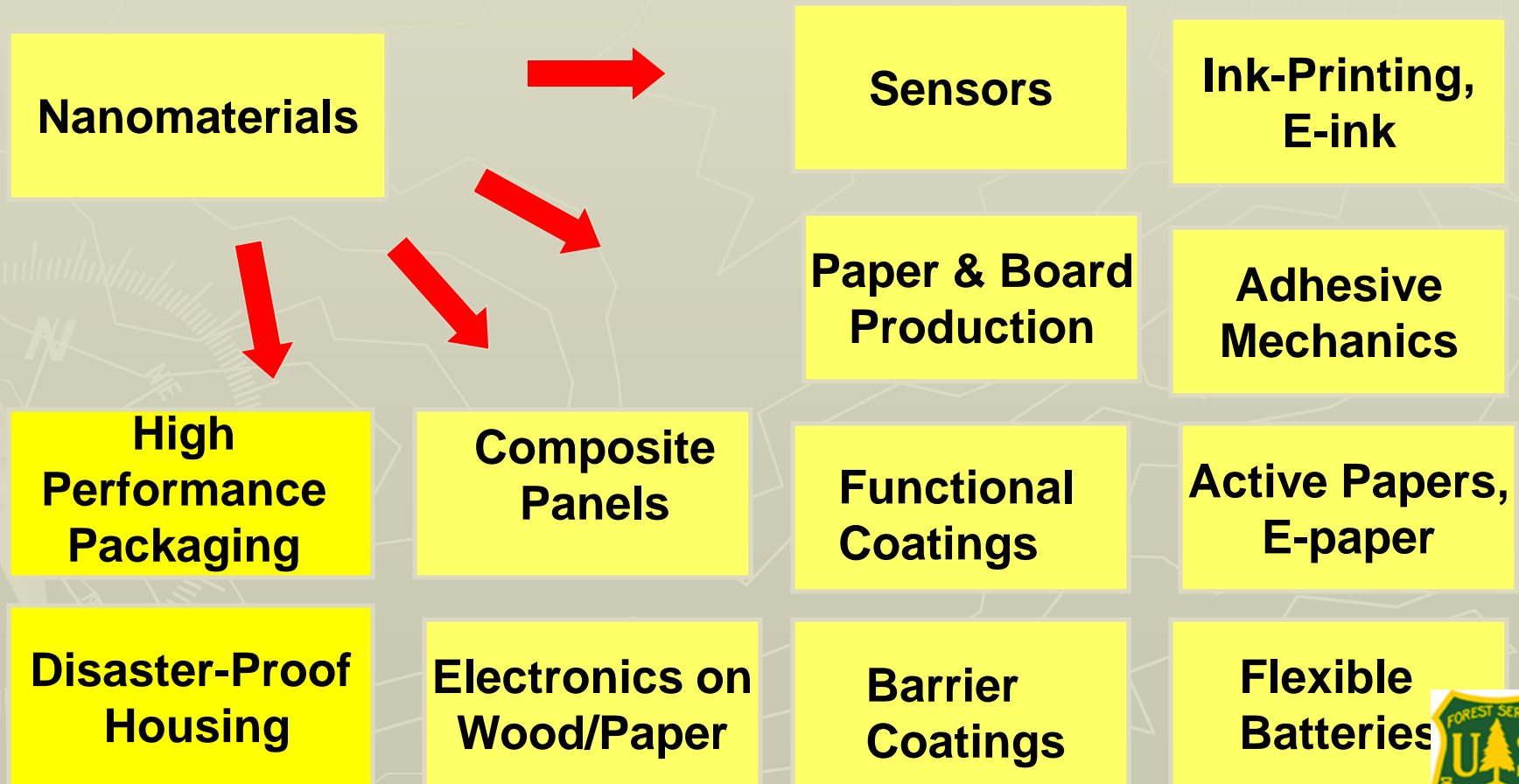
Acid Hydrolysis

<sup>1</sup>Alan Rudie & Richard Reiner (US Forest Service, Forest Products Laboratory)



# Application of Nanotechnology

- Improve Durability Performance & Functionality
- Incorporate Nanomaterials into Products



# Desired Nano-enabled Features

- **High Strength & ultra-light weight (e.g. Modulus 250 – 950 GPa, Tensile 11 – 63 GPa, density less than 1.5 g/cc)**
- **Charge Dissipation/Electrical Conductivity**
- **Photonic & Magnetic effects**
- **Piezoelectric/electrical effects**
- **Thermal Properties**
- **Nanocatalysis**
- **Multifunctionality**
- **Self-healing**



# Cellulose Nanocrystals

- **High strength ( $\sim$ Kevlar fibers; 0.15 – 0.25 of carbon nanotubes)**
- **Piezoelectric (Equivalent to Quartz)**
- **Commercial potential**
  - **Relatively Inexpensive compared to carbon nanotubes (est.  $\sim$ \\$8/kg)**
  - **Renewable & producible in bulk**
  - **Microcrystalline cellulose (MCC) already used in food & pharmaceuticals**
  - **Currently  $\sim$ 100k ton/yr demand for MCC**



# Research Efforts

- **Photonic effects of nanomaterials**
- **Imaging and holography with nanoparticles**
- **Liberation and fractionation of cellulose nanocrystals from wood**
- **Chemical modification of surfaces of cellulosic nanomaterials**
- **Processing nanomaterials in manufacture of composites**
- **Investigation of the range of nanomaterials obtainable from wood**



Questions?

